EPFL

PHYS-410

Cold atoms and quantum simulation

Brantut Jean-Philippe

Cursus	Sem.	Type
Ing.-phys	MA2, MA4	Opt.
Physicien	MA2, MA4	Opt.

Language of teaching	English
Credits	4
Session	Summer
Semester	Spring
Exam	Oral
Workload	120h
Weeks	14
Hours	**4 weekly**
Courses	2 weekly
Exercises	2 weekly
Number of positions	

Summary

This course describes the concept of quantum simulation and its implementation using cold atomic gases. The experimental tools and core theoretical concepts are presented, together with a few topics of ongoing research in the field.

Content

Basic tools of the physics of cold atoms:

1. **Laser cooling and trapping**: basics of atomic physics, alkali atoms. Reminders on light matter interactions, forces on two-level atoms.
2. **Effective Hamitonians**: adiabatic elimination of fast degrees of freedom, moving frames, Floquet Hamiltonians
3. **Optical lattices**: band theory and tight binding models, fundamental exemples
4. **Bose-Einstein condensation**: reminders of quantum statistical mechanics, trapped gases. Experimental aspects.
5. **Bogoliubov theory of Bose-Einstein condensation**: second quantization, Gross-Pitaevskii equation and applications to vortices and solitons.
6. **Interactions between atoms**: s-wave scattering, Feshbach resonances

Fundamental exemples of quantum simulations with cold atoms, chosen among:

1. **Interacting atoms in a lattice**: Bose-Hubbard model, Superfluid to Mott insulator phase transition, Fermi Hubbard models.
2. **Quantum transport and disordered systems**: Anderson localization, the Bose glass, many-body localization
3. **The unitary Fermi gas**: Leggett theory of the BEC-BCS crossover, universality and Tan's relations
4. **Topological systems**: artificial gauge fields and spin orbit coupling schemes, Haldane and Harper-Hofstatter models

Learning Prerequisites

Required courses

Quantum electrodynamics and quantum optics

Recommended courses

Solid state physics III

Important concepts to start the course

Basic quantum mechanics: hydrogen atoms, harmonic oscillators, two level systems, perturbation theory
Basic statistical mechanics: quantum statistics, density matrices
Quantum optics: two level system in an external field, Optical Bloch equations, stimulated and spontaneous emission

Learning Outcomes

By the end of the course, the student must be able to:
- Describe the basic ingredient of cold atoms experiments
- Analyze scientific articles in the field of cold atoms
- Recall the most significant outcomes of quantum simulation with cold atoms

Transversal skills

- Summarize an article or a technical report.
- Make an oral presentation.

Teaching methods

Lectures and exercise classes, paper clubs: each student will be given one research article to read and analyze, and then expose in class.

Expected student activities

Completed exercise sheets to be corrected every week.

Assessment methods

Oral exam

Supervision

Assistants	Yes

Resources

Virtual desktop infrastructure (VDI)

No

Bibliography

Statistical mechanics, Kerson Huang
Laser cooling and trapping, Metclaf and Van der Straten
Bose-Einstein condensation and Superfluidity, Pitaevskii and Stringari
Quantum Fluids, Anthony Leggett
Atomes et Rayonnements, lectures by Jean Dalibard at Collège de France

Ressources en bibliothèque

- Quantum liquids / Leggett
- Atomes et rayonnement / Dalibard
- Bose-Einstein condensation in dilute gases / Pethick; Smith
- Laser cooling and trapping / Metclaf; Van der Straten
- Statistical mechanics / Huang

Prerequisite for

Advanced topics in Quantum Science and Technology, Specialization and Master projects in cold atoms, PhD thesis.